The influence of transient surface fluxes on North Atlantic overturning in a coupled GCM climate change experiment

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Abstract.
The mechanism by which the model-simulated North Atlantic thermohaline circulation (THC) weakens in response to increasing greenhouse gas (GHG) forcing is investigated through the use of a set of five multi-century experiments. Using a coarse resolution version of the GFDL coupled climate model, the role of various surface fluxes in weakening the THC is assessed. Changes in net surface freshwater fluxes (precipitation, evaporation, and runoff from land) are found to be the dominant cause for the model's THC weakening. Surface heat flux changes brought about by rising GHG levels also contribute to THC weakening, but are of secondary importance. Wind stress variations have negligible impact on the THC's strength in the transient GHG experiment.

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Table 1. Forcings of the Coupled Model Experiments

Experiment	Radiative Forcing	Ocean P-E+R Forcing	Ocean Wind Stress Forcing
CONTROL	Constant	Model-predicted	Model-predicted
TRANSIENT	Transient GHG+SUL	Model-predicted	Model-predicted
CRAD_TH2O	Constant	P-E+R from TRANSIENT	Model-predicted
TRAD_CH2O	Transient GHG+SUL	P-E+R from CONTROL	Model-predicted
CRAD_TWIND	Constant	Model-predicted	Winds from TRANSIENT

A set of five coupled GCM experiments are utilized to determine the roles that changes in various surface fluxes have on the North Atlantic thermohaline circulation in simulations with imposed, transient atmospheric radiative forcing.

The segment of the CONTROL (constant GHG levels) simulation examined here is 330 years in length and begins 1100 years after the coupled model was initialized.

The TRANSIENT experiment is initialized from the CONTROL simulation's state at the start of model year 1101. This point in time represents 1 Jan. 1766 for purposes of the GHG and tropospheric sulfate aerosol (GHG+SUL) forcing scenario.

Three additional 330-year long model experiments are conducted to shed light on the role of changing surface fluxes on the TRANSIENT run's climate response.

In experiment CRAD_TH2O, atmospheric GHG levels are held constant, but the ocean-sea ice component of the coupled model is forced with the 330-year long time series of daily varying *P-E+R* fluxes archived during the TRANSIENT experiment.

In TRAD_CH2O simulation, the transient GHG and sulfate aerosol scenario is prescribed for the atmospheric GCM, but the time series of daily *P-E+R* fluxes from the CONTROL run is imposed upon the ocean-sea ice component.

To determine the role that wind stress changes play in altering the THC, in experiment CRAD_TWIND, atmospheric GHG levels are held constant, but the 330-year long time series of daily wind stresses archived during the TRANSIENT experiment are imposed on the ocean-sea ice component.

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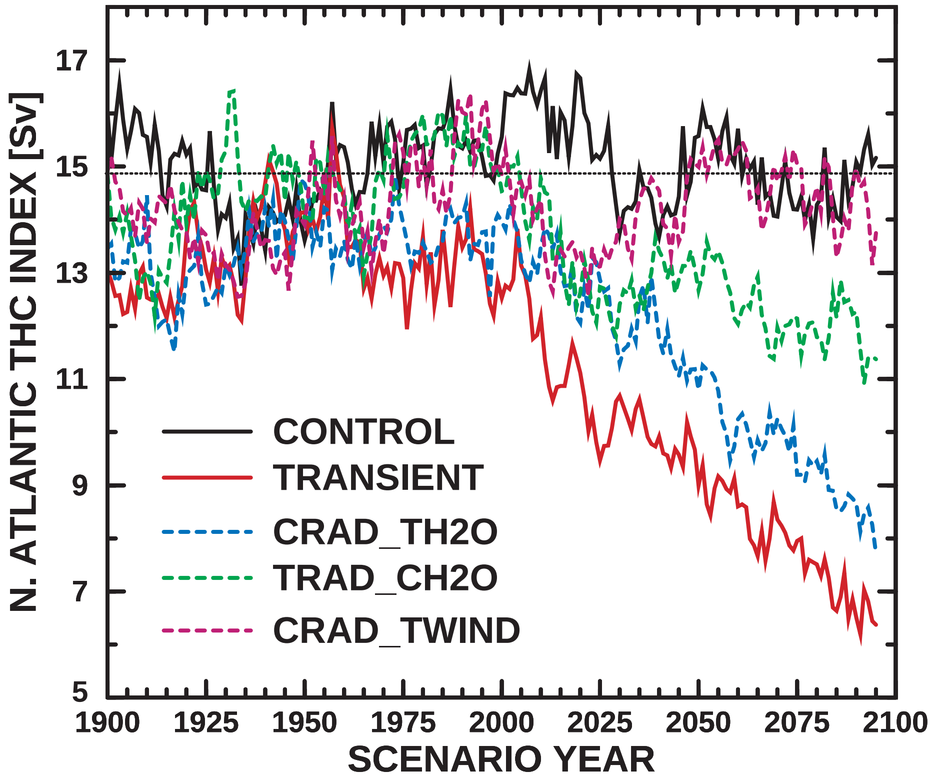
FIG. 1



Time series of annual mean North Atlantic THC indices produced by the five coupled GCM runs for the period corresponding to scenario years 1900 to 2095 (years 1766 to 1899 not shown for clarity). Horizontal black line at 14.9 Sv indicates the CONTROL run's 330-year mean.

These results indicate that *P-E+R* changes are the predominant reason for the weakening of the North Atlantic THC in the TRANSIENT run. Surface heat flux changes that occur in the coupled GCM during the TRANSIENT run also contribute to THC weakening, but are of secondary importance (they can reduce surface water densities by melting sea ice and by the thermal expansion that occurs as near-surface waters warm). The results of experiment CRAD_TWIND show that wind stress changes have negligible impact on the TRANSIENT run's THC strength.

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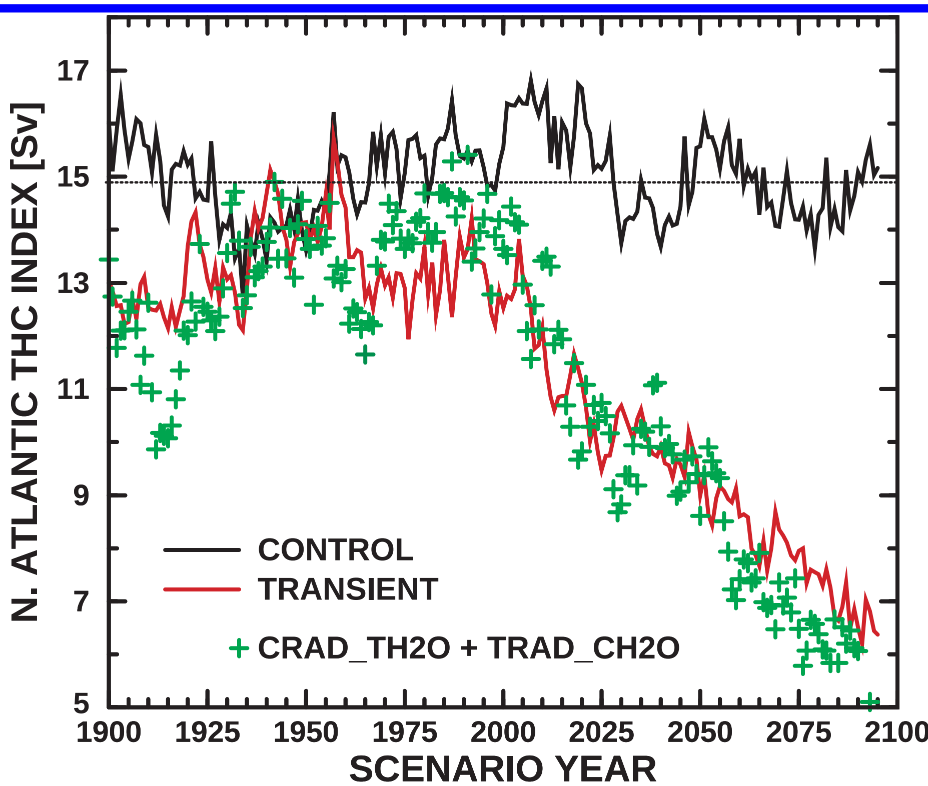
FIG. 2



As in Fig. 1, black and red lines show the CONTROL and TRANSIENT runs' THC indices. The green crosses show the additive effects of the CRAD_TH2O and TRAD_CH2O THC index responses (computed separately as deviations from the CONTROL's 330-year mean of 14.9 Sv, and then summed).

The results of adding together the THC index responses of the CRAD_TH2O and TRAD_CH2O model runs are shown above. During the period of rapid THC weakening, the sum of these two responses roughly approximates that of the TRANSIENT experiment's THC response. The amount of variability present within the THC time series and the fact that this analysis includes just one set of model experiments preclude a more quantitative assessment of the extent to which these are truly additive effects.

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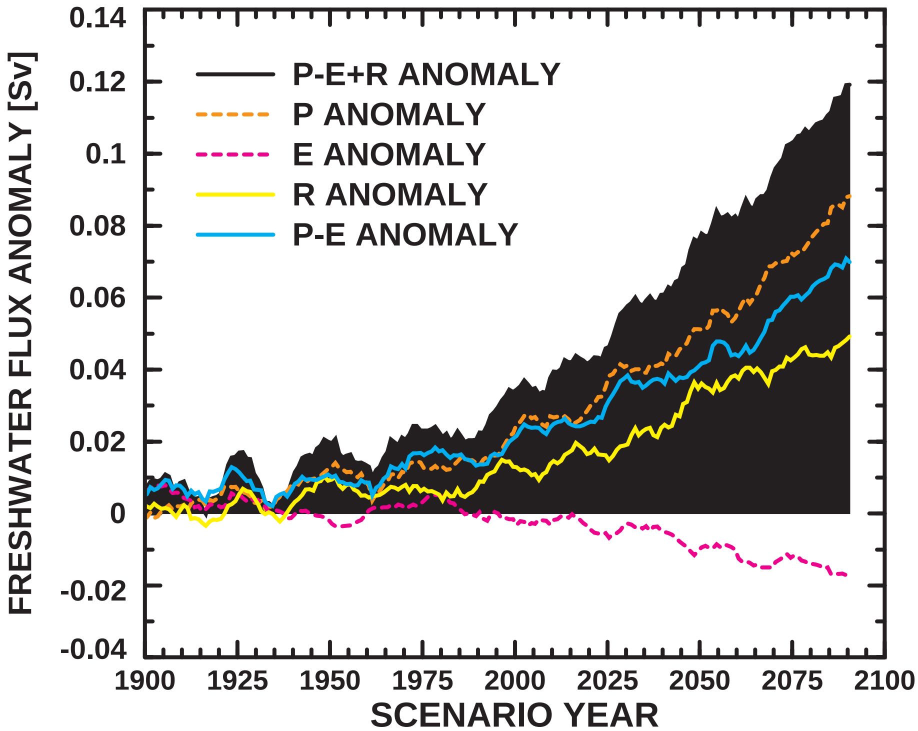
FIG. 3



10-year running means of the TRANSIENT run's freshwater flux anomalies integrated over the Arctic and North Atlantic north of 50^{o}N. Anomalies are computed relative to the CONTROL run's 330-year means. The black area represents the *P-E+R* anomalies. Solid cyan and yellow curves show the *P-E* and runoff terms, respectively. Dashed orange and magenta curves show precipitation and net evaporation anomalies over the ocean, respectively.

On decadal time scales, surface water fluxes (liquid and solid) in this domain (the Arctic Ocean and North Atlantic north of 50^{o}N) presumably influence surface salinities where the model's version of North Atlantic Deep Water is formed. Over the region of integration, both runoff and net *P-E* contribute to the increased net surface freshwater flux passed to the TRANSIENT run's ocean-sea ice component. During the last 50 years of the simulation, runoff from the land surface accounts for ~43 percent of the increase in *P-E+R*.

Summary:

The set of coupled GCM experiments examined here reveals that changes in surface freshwater fluxes (*P-E+R*) are the primary reason that the North Atlantic meridional overturning weakens in coarse resolution GFDL coupled model simulations forced with increasing GHGs. Surface heat flux changes play a secondary role in weakening the THC, while wind stress changes have negligible impact. The dominance of the freshwater flux term becomes very clear during the second half of the model-simulated 21st century.

Over the Arctic Ocean and North Atlantic north of 50^{o}N, increases in precipitation and runoff are larger than the increase in net evaporation. These changes contribute to lower surface salinities and densities in the ocean model, which lead to reduced North Atlantic deep water formation rates (lower THC index). Changes in surface heat fluxes that occur when transient atmospheric radiative forcing is imposed lead to warmer SSTs and surface freshening as sea ice melts. By reducing surface water densities in these ways, the surface heat flux changes also contribute to weakening the model's THC, but to a lesser extent than the *P-E+R*.

The results reported here are specific to the coarse resolution GFDL coupled model. The THC of different models will respond differently to increasing GHG forcing. And even in models that yield similar THC responses, different mechanisms may dominate.

http://www.gfdl.gov/~kd/

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